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V. A. Bronshten

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ORIGIN OF THE ASTEROIDS

V. A. Bronshten *

ABSTRACT. The origin of the asteroids is discussed in light of the current state of knowledge. The topics include asteroid orbits and masses, asteroid distribution according to periods, the history of asteroid fragmentation, and the disintegration of the hypothetical planet Phaeton. Some details are given on a Phaeton model proposed by Zavaritskiy according to which iron-nickel meteorites are fragments of the nucleus, iron-stone meteorites are fragments of the middle layer, and stone meteorites are fragments of the mantle of the exploded planet.

The editorial staff of "Zemlya i Vseleennaya" received several letters from readers asking us to tell about the origin of the asteroids. In particular, they are interested in the hypothesis of the disintegration of a planet Phaeton, whose fragments are the asteroids. And a reader Olga S. from Leningrad asks: "Do our scientists know that the Phaetonites were highly developed people?" Various aspects of the problem of the origin of the asteroids and the hypothesis of Phaeton are discussed in the article published below.

First of all, I will answer the question of Olga S. No, my esteemed Olga, scientists do not know whether the Phaetonites were highly developed beings (you said "people" — well, why so straightforward?). They do not know whether or not these imaginary Phaetonites existed at all. To judge and guess about such things is the task of fantasists and not of scientists. Unfortunately, scientists, carefully analyzing the facts, cannot even say

* Candidate of Physico-mathematical sciences.

** Numbers in the margin indicate pagination in the original foreign text.

whether or not there was a planet Phaeton. And the facts are a stubborn matter.

In this article I want to lead the reader over the complicated labyrinth of the problem of the "origin of the asteroids" without glossing over the difficulties, smoothing over the contradictions, or attempting to give a definitive answer to the problem.

The Ring of Asteroids

The history of the discovery of the first four asteroids is sufficiently well known. Back in 1796 at a congress in Gotha a group of 24 astronomers was organized for the purpose of finding the "missing" planet between the orbits of Mars and Jupiter. Such a planet should exist at a distance of 2.8 A.U. from the Sun on the basis of the Titius-Bode rule. They began to search for the planet. And on January 1, 1801, G. Piazzi discovered it, and a year later H. Olbers found another planet at the same distance from the Sun. Thus, the first two asteroids, Ceres and Phallas, were discovered.

The discovery of two planets instead of one led Olbers in 1804 to the idea that these are the fragments of a large planet which somehow broke up into pieces. Soon two more asteroids, Juno and Vesta, were found, and after 1845 the discoveries came with increasing frequency. Up to the present time 1767 asteroids with well-determined orbits are known to astronomers. Names and numbers have been assigned to these asteroids. Several thousand other minor planets still have only preliminary designations.

In order to approach a solution of the problem of the origin of the asteroids, it is necessary to discuss, first of all, what place they occupy in the solar system.

If one plots the orbits of the asteroids on a diagram of the solar system, it is easy to convince oneself that the majority of them form a ring or belt

of asteroids between the orbits of Mars and Jupiter. The semimajor axes of the orbits of 97% of minor planets lie between 2.17 and 3.64 A.U., amounting, on the average, to 2.75 A.U.

A considerable number of minor planets pass outside the limits of the ring. Nineteen asteroids of the Eros-type (the well-known Icarus is among them) pass inside the ring in the direction of Mars, Earth, and the Sun. Nineteen asteroids of the Hilda group with almost identical orbits (semimajor axes of 3.9 - 4.0 A.U.), 15 of the so-called Trojans which move in Jupiter's orbit at an angle of 60° in front of or behind it⁽¹⁾, and three individual asteroids Oda, Thule, and Hidalgo move beyond the outer limits of the ring.

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Orbits and Masses

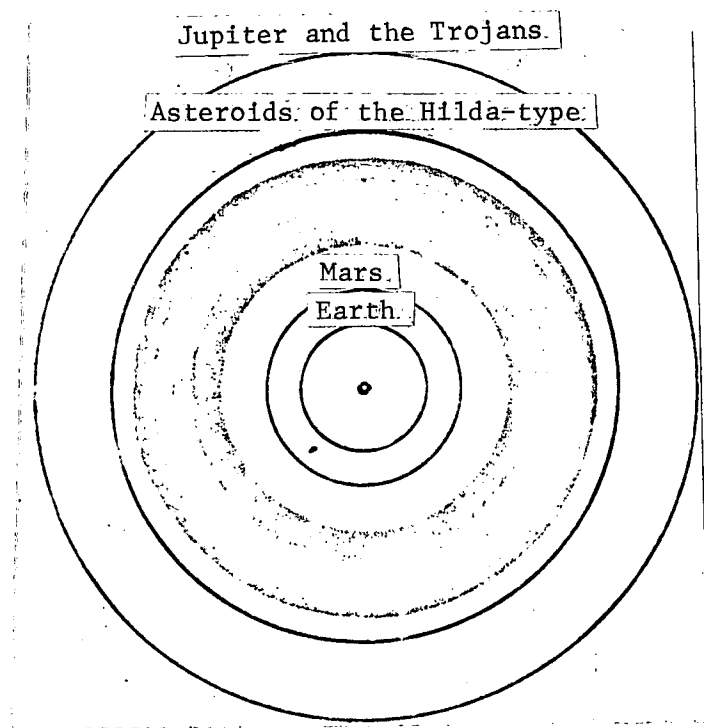
We will compare such characteristics of asteroidal orbits as the eccentricities and the inclinations with the analogous elements of the orbits of the major planets and of comets.

The major planets move in orbits which are nearly circular (the eccentricity is no greater than 0.25) and with small inclinations (no greater than 17°). Some minor planets have orbits which are more extended: the eccentricity reaches 0.83, and the inclination to the ecliptic plane attains a value of 52° . Comets move in highly elongated orbits which are practically parabolas and which have any inclination to the ecliptic.

Thus, on the basis of these characteristics, the minor planets occupy an intermediate position between the major planets and comets. One should bear in mind the fact that only 40 asteroids have eccentricities greater than 0.34, and only 100 asteroids have inclinations greater than 20° . On the other hand,

(1)

Among the numbered asteroids there are a total of 15 Trojans, although more of them have been discovered in recent years; orbits have been calculated for 29 Trojans, and their total number reaches 700 according to data of the Mount Palomar Observatory.



The asteroid belt.

and comets and also concerning the origin of asteroids from comets (there have been such hypotheses).

We will now consider the very important characteristic of the mass of the asteroids. There are not yet reliable direct determinations of the masses of these objects, and we must use indirect estimates. We will start with the largest asteroid Ceres. Knowing the diameter of Ceres to be 770 km, assuming it to be spherical in shape, and assuming an average density of 3 g/cm^3 , we obtain a mass of 7×10^{17} metric tons, or $7 \times 10^{23} \text{ g}$ ⁽²⁾.

In this way we will find a mass of $1.5 \times 10^{15} \text{ g}$ for an asteroid with a size of 1 km (of the Adonis or Hermes type). We will compare the range of

⁽²⁾ Recently I. Shubert determined the mass of Ceres from the perturbations during a year in the motion of Pallas and got a value of $1.3 \times 10^{24} \text{ g}$.

only three comets have eccentricities less than 0.40. If one adds to this situation the fact that even short-period comets have semimajor axes of their orbits from 3 to 18 A.U. (not considering Comets Encke and Wilson-Harrington), i.e., they go out far beyond the limits of the asteroid belt, it becomes clear that there is evidently no direct genetic resemblance between these two groups of small objects of the solar system. Therefore, it is necessary to discard hypotheses concerning the joint formation of asteroids

masses of asteroids and of other members of the solar system.

Major planets	$3 \cdot 10^{23}$ — $2 \cdot 10^{20}$
Minor planets	10^{15} — 10^{24}
Comets	10^{14} — 10^{20}

And thus minor planets are significantly inferior in mass to the major planets, but they are comparable in mass to comets. The masses of comets are not very accurately known.

Only the largest asteroids (of the Ceres type) can be assumed to have a spherical shape. The presence of some minor planets having periodic brightness variations has compelled us to assume them to be fragments of irregular shape which are rotating with a period of from 2 to 9 hours. Direct observations of the asteroid Eros during its approach to the Earth showed that it has an elongated shape with a length of 22 km and a width of about 6 km. The asteroid Icarus also has an irregular shape with "dimensions" of 0.6 x 1.2 km.

The Hirayama Families

Studying the distribution of asteroids with respect to their orbital elements, K. Hirayama proceeded from Olbers' hypothesis of the destruction of primary planets. Knowing how large the effect of the perturbing forces is, especially those due to Jupiter, the Japanese scientist decided to select for further analysis those combinations of orbital elements in which the action of secular perturbations does not appear. Having calculated these variables, or the elements themselves, for 1223 asteroids, Hirayama discovered five groups of minor planets with almost identical elements. He gave them the designation of families, having denoted each by the name of a typical minor planet. Thus there appeared the Themis, Eos, Koronis, Maria, and Flora families. Subsequently, about 30 more families containing 450 asteroids were found. The existence of families led to the idea that the asteroids of each

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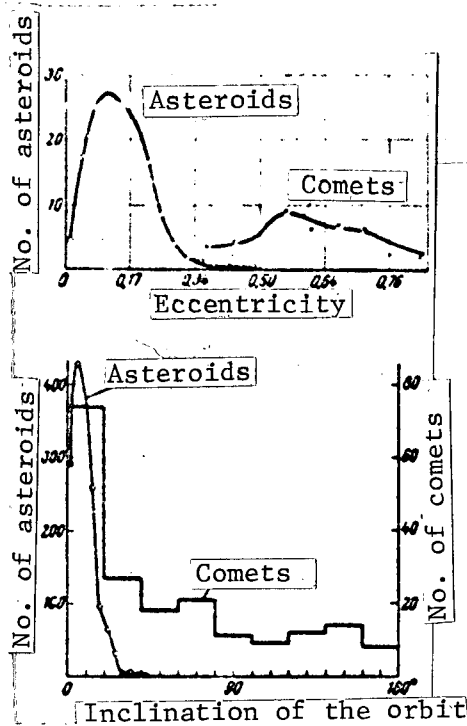
family have a common origin; in other words, they are the fragments of some larger asteroid, the "father of the family".

But since some tens of families are known, the parent planet was as large as or larger than the "fathers of the families". It means that it is impossible to explain all the numerous orbits of the asteroids by a single disruption. It is necessary to assume a series of consecutive disruptions: first, of the original planet into a number of sufficiently large fragments (the "fathers of the families"), and then the disruption of these fragments into smaller ones (the contemporary asteroids which make up the families).

The Soviet astronomer I. I. Putilin advanced such a hypothesis in 1949, having calculated for all the asteroids which make up the families the value of the Jacobi constant, a quantity with the dimension of energy which does not change under the influence of Jupiter's perturbations. This quantity is equal to the energy which the asteroid received at its formation. The equality of the Jacobi constants for members of families indicated similar conditions for their formation. It was possible to determine from the scatter of these quantities within the families the velocities acquired by the fragments upon being broken up. They amounted to about 100 m/sec for the Themis, Eos, Koronis, and Maria families, about 300 m/sec for the Flora family, and to somewhat larger values for the Focaea and other families.

The History of the Breaking Up of the Asteroids

For the last 20 years, the director of the Shemakhinskaya Astrophysical Observatory, G. F. Sultanov, has investigated this problem by the methods of celestial mechanics. In his doctoral dissertation he showed that it is impossible to explain the variety of the orbits of asteroids by the disruption of a single planet but only by the breaking up of several parent objects. G. F. Sultanov established that it is possible to divide up the entire class of asteroids into 12 groups on the basis of the values of their own elements.



Distribution of asteroids and comets with periods less 20,000 years with respect to their eccentricities (above) and the inclinations of their orbits (below). There is a noticeably distinct difference in the distribution of both groups of celestial objects.

the same, although study of four of the largest of them shows that this is not quite the case.

Anders constructed a graph of the distribution of asteroids with respect to their absolute stellar magnitudes. It turned out that the distribution of the bright asteroids corresponds to a Gaussian curve, while the number

On the basis of the scatter of the orbital elements of the asteroids of a single group, G. F. Sultanov estimated the dispersion velocity of the fragments; it could not exceed 10% of the primary object's orbital velocity.

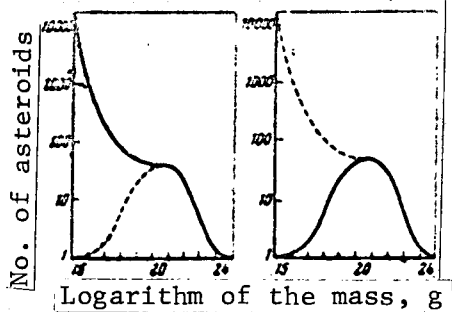
The American investigator E. Anders approached the study of the history of the breaking up of asteroids in a different fashion. He used their distribution with respect to absolute stellar magnitude⁽³⁾. This quantity is proportional to the logarithm of the dimensions (or the masses) of an asteroid, since the brightness depends on the dimensions and albedo, and the mass is determined by the dimensions and the density. Anders assumed the albedo and density of all the asteroids to be

(3) By the absolute stellar magnitude of an asteroid is meant the conventional stellar magnitude which it would have if it were at opposition at a distance of 1 A.U. from the Earth and the Sun (these conditions can not actually be fulfilled).

1 of faint asteroids follows a logarithmic law. Then Anders conceptually
2 "gathered" asteroids making up the Hirayama families into their parent objects
3 and plotted the points obtained for them on the graph. They lay on the
4 Gaussian curve, but the "population" of the logarithmic component of the
5 curve decreased. Anders repeated the operation, "gathering" into single
objects unnamed families which had disintegrated. The logarithmic branch
disappeared, leaving only the Gaussian distribution, which corresponded to
the initial state. Then Anders drew a number of interesting conclusions.
In the first place, there were several stages (phases) of breaking up. In
the second place, the half-life period (loss of half the mass) of asteroids is
equal to approximately 6 billion years; during the last 4.5 billion years
the total area of their surface has increased by only 6% due to breaking up.
In the third place, the half-life period of the Hirayama families is about
2 billion years.

In 1968 the Hartmanns continued Anders' work. Having adopted the distri-
bution derived by Anders as the initial Gaussian distribution of the asteroids
by mass, they discussed how this distribution was changed. It turned out
that the parent objects of the contemporary fragmentary asteroids were 5 - 30
objects with masses of the order of 10^{21} g which underwent from 4 to 18
break-ups. /56

The American scientist G. Donenyi discussed the problem of the breaking
up of asteroids from a somewhat different point of view. Having investigated
the mechanics of collisions and taking into consideration their effect on the
distribution of fragments with respect to their masses for a specified
collision velocity (or distribution of velocities), he arrived at a conclusion
concerning the power law of the distribution of fragments with respect to mass.
The exponent is equal to $11/6$, which is very close to the observed exponent
5 $9/5$. Such a distribution is a stationary one; it does not change in the
6 course of subsequent breakups, at least not for objects with mass less than
7 10^{10} g. Larger objects will slowly be broken down: collisions of small
8 objects will "scrape off" a 1 m layer from them in 1 million years. The
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Distribution of the asteroids with respect to mass (according to E. Anders): on the left is the original distribution, and on the right is the distribution after the "regeneration" of the parent objects of the families. The distributions for each scheme is shown by a solid curve; the dashed curve is shown for the convenience of their comparison. The symmetrical curve is called a Gaussian curve; the branch which rises upward is part of a logarithmic curve.

lifetime of large asteroids is measured in billions of years. The total mass of all the asteroids in the case of such a distribution is about 5×10^{23} g, i.e., no larger than the mass of Ceres. Annually it is subjected to the breakdown of 10^{15} g mass, and the asteroid belt on the whole loses (as a result of the large velocities of the fragments, perturbations by the planets, and so on) about 6×10^{18} g.

And so the application of the most varied methods of analysis of the astronomical data on the asteroid belt has given results which argue against the hypothesis of the unique disruption of a single planet and in favor of the hypothesis of numerous break-ups. But from what did these break-ups begin? Where did the original objects come from?

How Could Phaeton Have Been Broken Up?

The hypothetical planet of Olbers was left nameless for a century and a half. Only in 1949 did the well-known Soviet astronomer S. V. Orlov give it the name Phaeton in honor of the unfortunate son of the sun king Helios, who took it into his head to go for a drive in his own father's chariot across the sky and who fell to the earth when the horses bolted... . This name has become established.

In 1949-1950 the hypothesis of the disintegration of Phaeton received, as it were, its second birth in the works of a number of great Soviet

1 scientists: Academician V. G. Fesenkov, Academician A. N. Zavaritskiy,
2 Corresponding Member of the USSR Academy of Sciences S. V. Orlov, Assistant
3 Professor I. I. Putilin, and others. The problem assumed to be the most
4 difficult at that time was: what led to the disintegration of Phaeton?
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Academician V. G. Fesenkov attempted in 1950 to explain the disinte-
gration of Phaeton by its close encounter with Jupiter. But for the planet
to be broken up into pieces, it would have to approach Jupiter very closely.
Meanwhile the orbits of the majority of asteroids are very far from Jupiter.
V. G. Fesenkov well understood the difficulties of his own model and later
rejected it.

I. I. Putilin proposed a more complicated scheme in 1953. He assumed
the cause of the disruption to be the rapid rotation of the planet. With a
diameter of 6800 km and a period of rotation of 2.6 hours the centrifugal
acceleration can balance the acceleration due to gravity. The ripping off
of the outer layers of the planet near its equator took place. The pressure
of the gases from within facilitated the subsequent disintegration of the
planet. I. I. Putilin considered not a single explosion but a number of
successive explosions of large fragments from which the asteroid families
were then formed. But the disruption models of Phaeton did not satisfy the
scientists. It was not physically justified.

The Odessan astronomer, Professor K. N. Savchenko, gave in 1955 a quite
different very beautiful explanation of Phaeton's break-up. He approached
this problem from the standpoint of celestial mechanics. Let us assume that
the planet Phaeton had five satellites: Ceres, Pallas, Juno, Vesta, and a
fifth satellite, the most distant from the planet. The fifth satellite was
located almost at the limit of Hill's sphere of stability⁽⁴⁾. The perturba-
tions by Jupiter resulted in the fact that the fifth satellite left the Hill's

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⁽⁴⁾ Hill's sphere is the region of space in which stable motion of a planet's
satellites is possible with respect to perturbations by the Sun. For the
planet Phaeton being imagined, the radius of Hill's sphere could amount to
2 million km.

1 sphere, went out beyond its limits, and became an independent planet; after
2 many millions of years had passed, it should have again entered the Hill's
3 sphere of the planet Phaeton, but this time it rapidly approached the planet
4 and collided with it. As a result of the impact Phaeton was broken up into
5 numerous fragments, and Ceres, Pallas, Juno, and Vesta became independent
planets.

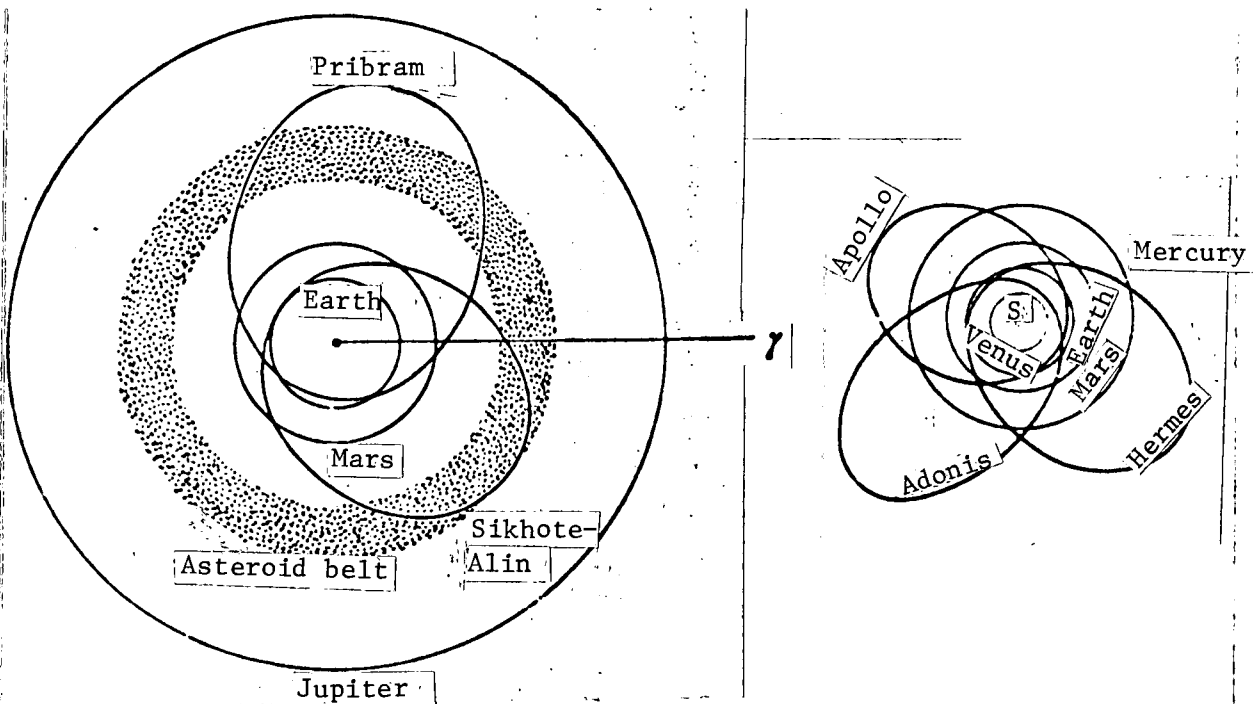
K. N. Savchenko did not succeed in publishing the calculations which he made in the verification of this hypothesis. After his arrival at the Conference on Comets and Meteorites at Odessa, at which this hypothesis was expounded, he soon died. And although a unique physically plausible explanation of Phaeton's destruction is given in K. N. Savchenko's hypothesis, it has encountered difficulties. As calculations show, an object only three times smaller than this planet, namely, an object with a diameter of about 2000 km, could break up a planet of the size of Mars at a most probable velocity of approach of 5 - 6 km/sec (the parabolic velocity for Mars is 5.1 km/sec). This is a bit too much for a satellite of Phaeton. If the satellite was of the same size as Ceres, the collision velocity should have reached approximately 20 km/sec. K. N. Savchenko understood this fact and proposed that the fifth satellite, moving past Phaeton several times, increased its velocity and angle of encounter each time. By the fifth passage it could attain a velocity of 17 km/sec. With such a velocity a collision took place. But while scientists have disputed how Phaeton was destroyed, a hypothesis has been successfully developed in our country, which does not at all abandon the place of the planet Phaeton in the solar system, namely, the hypothesis of Academician O. Yu. Shmidt.

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Asteroids and Meteorites

5 A great inadequacy of the hypotheses with which the reader has become
4 acquainted was the fact that the probable connection of asteroids with
3 meteorites was not taken into consideration in these hypotheses. Actually,
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Orbits of meteorites: Sikhote-Alin and Pribram (on the left) and asteroids of the Apollo type (on the right).

if small asteroids are formed in the course of the break-up of comparatively large objects by their collisions with one another, still smaller fragments should arise thereby which we are not able to observe by astronomical methods but which can, upon encountering the Earth, strike it. The mass of the meteorite which formed the famous Arizona crater is estimated to be 10^{11} g, which is four orders of magnitude less than the mass of the smallest asteroids. Craters of clearly meteoritic origin have been found on the Earth which are far larger than the Arizona crater⁽⁵⁾. The diameter of some of these craters (Bosumtwi, Ries, and Vredefort) is measured in tens of kilometers, and the diameter of the gigantic Popigay crater in Siberia is about 100 km. Objects with mass of about 10^{15} - 10^{18} g could form them, i.e., asteroids of the

(5) E. L. Krinov, "New Information about Meteorite Craters", Zemlya i Vseleennaya, No. 5, 1966.

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2 Adonis or even the Eros type. This fact means that the masses of gigantic
3 meteorites and small asteroids are not very different.

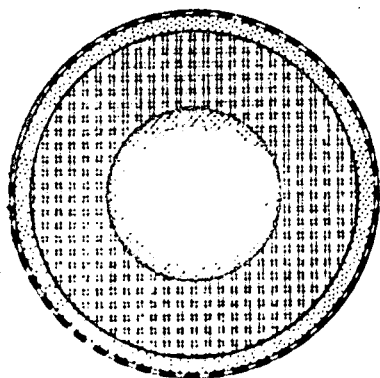
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5 If asteroids and meteorites have a common nature and origin, we obtain
the richest set of facts relating to meteorites for the explanation of the
problem of interest to us, which is their distribution with respect to
dimensions and masses, and information mainly about their structure, chemical
and mineralogical composition, and age.

The concept of "kinship" of asteroids with meteorites is encouraged by a
comparison of their orbits. It is true that the orbits of only a few meteorites
are known. More or less reliable orbits have been calculated for the Sikhote-
Alin meteorite and for the Pribram meteorite, which was photographed during
its fall by a meteor patrol. They resemble the orbits of asteroids of the
Apollo type, which passes inside the orbit of Mars. The same can be said of
several tens of meteorite orbits calculated with less accuracy; almost all
these meteorites have come to us from the asteroid belt. It is known that
meteorites never occur in connection with meteor streams; no connection of
them with comets has been discovered.

And so we will assume that asteroids and meteorites have a common origin.
What can an investigation of meteorites tell about them?

In 1948 Academician A. N. Zavaritskiy was one of the first scientists
to attempt to include the contemporary data of meteoritics in the solution of
this problem. Assuming that iron-nickel meteorites are the fragments of
Phaeton's core, iron-stony meteorites the fragments of an intermediate layer,
and stony meteorites the fragments of the mantle, A. N. Zavaritskiy constructed
a model of the disintegrating planet. A core with a radius of 1000 - 1200 km,
or 40% of the planet's radius (55% of the Earth's radius), occupies 6.5% of
its volume. Above it is located a transition zone of silicate material of
peridotitic composition with an admixture of iron which increases continually

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-  iron-nickel core
-  iron-silicate envelope
-  vitreous peridotitic layer
-  crystalline peridotitic envelope
-  basaltic layer (crust)

Model of the structure of the planet Phaeton (according to A. N. Zavaritskiy).

indirectly the radius of Phaeton at 3000 km, proposed a "reconstruction" similar to that of A. N. Zavaritskiy.

towards the center (just as for iron-stony meteorites) with a thickness of 3.5% of the object's radius; then a peridotitic envelope (mantle) similar in composition to chondrites (the most widespread class of stony meteorites) and occupying 55% of the object's radius. And finally there is a crust similar to the Earth's basaltic envelope and corresponding in composition to achondrites, which are stony meteorites of fine-grained structure. The crust accounts for 1.5% of the planet's radius or 40-45 km.

Five years ago the American meteoriticist R. Daly, who estimated

However, A. N. Zavaritskiy well understood that it is not enough to combine meteorites and asteroids mechanically into a "parent" planet, having separated them layer by layer. It was necessary to explain the distinctive features of the morphology and composition of meteorites by taking account of those conditions which should have reigned in each layer, having taken into consideration the processes which accompanied the break-up of the planet and the separation of the fragments. And then difficulties and contradictions arose. For example, it was necessary to assume that the pressure at the boundary of the iron core was not less than 150,000 atm. But under such pressures the phase transitions of iron which lead to the formation of the well-known Widmanstätten figures of iron meteorites could not have occurred.

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Structure of a stony meteorite, a chondrite. The small spheres, the chondrules, are visible as well as the interchondrule material.

It was necessary to explain one more phenomenon. The overwhelming majority of meteorites which have been observed upon their fall (92%) are the stony meteorites, and 95% of them are chondrites, which are glued together from small spheres of almost exclusively peridotitic composition, namely, chondrules, which resemble solidified droplets of molten glass. The spaces between the chondrules are filled with fine-grained material of the same composition. A. N. Zavaritskiy cited

the key problem in the origin of the chondrules, whose final solution may result in the solution of the general problem of the origin of asteroids and meteorites. Doctor of Physico-Mathematical Sciences B. Yu. Levin, one of the most important coworkers and perpetuators of the cosmogonic investigations of Academician O. Yu. Shmidt, adheres to the same point of view, but he pictured the solution of this problem to himself in a quite different fashion.

First of all, some contradictions have appeared in the mechanism of the formation of chondrites and "chondrules" proposed by A. N. Zavaritskiy. Chondrules were formed, according to A. N. Zavaritskiy, of droplets of an incandescent haze into which the disintegrating planet's mantle was converted. On the other hand, its crust was somehow crushed into solid fragments, the achondrites. The cooling of the chondrules should have taken place very rapidly; if not they would have had time to recrystallize, and only the beginning of the crystallization phase is observed in enormously large

1 chondrules. At the same time iron drops evidently did not cool rapidly, and
2 they were deformed and "fused" into larger particles, since chondrules are
3 almost never encountered in iron meteorites. A. N. Zavaritskiy assumed that
4 an explosion did not occur upon the disruption of the planet which gave rise
5 to the meteorites, but some other kind of process of pulverization occurred,
since intermixing did not take place. Sketching a rather complicated mechanism
for such a process, A. N. Zavaritskiy noted in his lecture at the First
Conference on Cosmogony (1951) that he thereupon treads upon the ground of
scientific fantasy.

Meanwhile, towards the middle of the 1950's, new facts were accumulated
which complicated the situation still more. The division even of uniform
meteorites into groups differing on the basis of their chemical and isotopic
composition was discovered. The American investigator G. Brown and his co-
workers, who considered the gallium and germanium content in iron meteorites,
came to the conclusion that there are four groups of meteorites. In 1953
H. Urey and H. Craig divided the chondrites into two groups which differed
in their total iron content. In 1955 A. A. Yavnel' found from data on the
nickel content in the metallic phase that meteorites are divided into five
groups. Only ten years later he exhibited some eight groups of chondrites
with respect to iron in different forms (metallic, oxide, and sulfide)⁽⁶⁾.

The minerals encountered in chondrites could have been formed, according
to an estimate of H. Urey, at a temperature no lower than 1500° C. This
situation should have occurred in some kind of "original" objects. Data on
the content of nickel in two phases of nickel-iron (kamacite and taenite)
and on the dimensions of their crystals have shown that the formation of
these two phases occurred by the slow cooling of a solid solution of nickel-
iron at temperatures up to 450-650° C and for a time of $10^7 - 10^8$ years.

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4 (6) A number of aspects of the problem of the origin of meteorites are eluci-
3 dated in the article "Fundamental Successes of Meteoritics" by V. G. Fesenkov,
2 Zemlya i Vselennaya, No. 6, 1968.
1

1 In order to explain these distinctive features, Urey was forced to assume
2 that the "primary" objects were broken up into small fragments, part of
3 which was melted and formed the chondrules. Fragments were combined into
4 "secondary" objects of asteroidal dimensions; in their turn they were broken
5 up and combined into "tertiary" objects (thus the breccia-like meteorites
occurred) and so forth.

From the Standpoint of Shmidt's Hypothesis

It was not possible to underestimate the difficulties associated with the multiplicity of groups of meteorites. They indicated that phase transitions in meteorites of various groups reached different stages, and this fact in its turn indicated the diversity of the rates of their cooling, and thus the dimensions of the parent objects from which they were formed.

Urey's complicated and not completely clear scheme was significantly inferior in its approach to this problem to O. Yu. Shmidt's cosmogonical hypothesis, in which objects of asteroidal dimensions are a regular stage in the development of planets⁽⁷⁾. From the point of view of O. Yu. Shmidt's hypothesis, the "secondary" and "tertiary" objects are not at all successive "generations" but objects existing simultaneously in an extensive cluster but traversing different courses of development due to the random nature of the collisions.

Although H. Urey and H. Craig attempted in 1953 to explain the two groups of chondrites which they found on the basis of the hypothesis that the asteroids arose from two parent planets, whereas A. A. Yavnel' advocated in 1955 that they resulted from five parent planets; the number of parent objects is in no way restricted from the point of view of O. Yu. Shmidt's hypothesis.

(7) B. Yu. Levin. "The Problems of Planetary Cosmogony in our Times", Zemlya i Vselennaya, No. 6, 1967.

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2 Why wasn't the material of the asteroid belt formed into a single large
3 planet? Evidently, the main reason was the perturbing effect of Jupiter.
4 Thus the asteroid belt probably doesn't consist of the fragments of a shattered
5 planet, but, on the contrary, of an incipient unformed planet.

As we have seen above, calculations of the processes of asteroid disintegration show that their age is comparable in order to magnitude with the age of the entire solar system, which is approximately equal to the age of the oldest rocks and meteorites. The ages of chondrites which have not undergone metamorphism amount to 4.3 - 4.5 billion years. Consequently, the asteroids, the Earth, and, as is now known, the Moon, have approximately the same age, i.e., they were formed simultaneously in a single process. O. Yu. Shmidt's hypothesis reconstructs such a process for us.

Nevertheless, we cannot consider the problem of the origin of the asteroids to be solved. The investigations are continuing.

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